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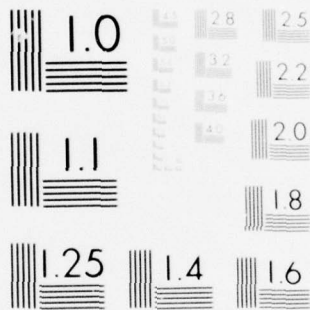
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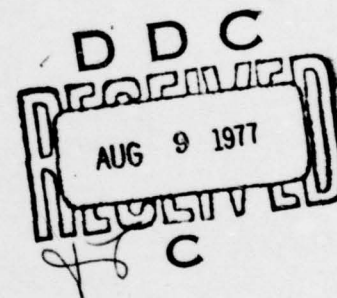
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DESIGN OF ELECTROSTATIC ANALYZER

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APRIL 1977

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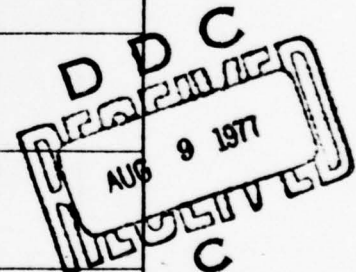
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20. ABSTRACT

This instrument is designed to detect and analyze precipitating electrons in the energy range from 50 eV to 20 keV. It is one of the supplementary sensors on board the Block 5D configuration satellites of the Defense Meteorological Satellite Program.

Differential energy analysis is performed by a pair of electrostatic analyzers (ESA) in which a time-sequenced variable electrostatic field deflects electrons of selected energies toward an exit aperture where they are counted by Channeltron Electron Multipliers (CEM). The small ESA covers energies ranging from 50 eV to 1 keV; the larger, 1 keV to 20 keV. The dwell time at each energy level is 98 ms, with both analyzers operating simultaneously. A complete 16 point spectrum is produced once per second and the 16 data words are transferred to the satellite on command. Figure 1 shows SSJ/3 with its test console.

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INTRODUCTION

This instrument is designed to detect and analyze precipitating electrons in the energy range from 50 eV to 20 keV. It is one of the supplementary sensors on board the Block 5D configuration satellites of the Defense Meteorological Satellite Program.

Differential energy analysis is performed by a pair of electrostatic analyzers (ESA) in which a time-sequenced variable electrostatic field deflects electrons of selected energies toward an exit aperture where they are counted by Channeltron Electron Multipliers (CEM). The small ESA covers energies ranging from 50 eV to 1 keV; the larger, 1 keV to 20 keV. The dwell time at each energy level is 98 ms, with both analyzers operating simultaneously. A complete 16 point spectrum is produced once per second and the 16 data words are transferred to the satellite on command. Figure 1 shows SSJ/3 with its test console.

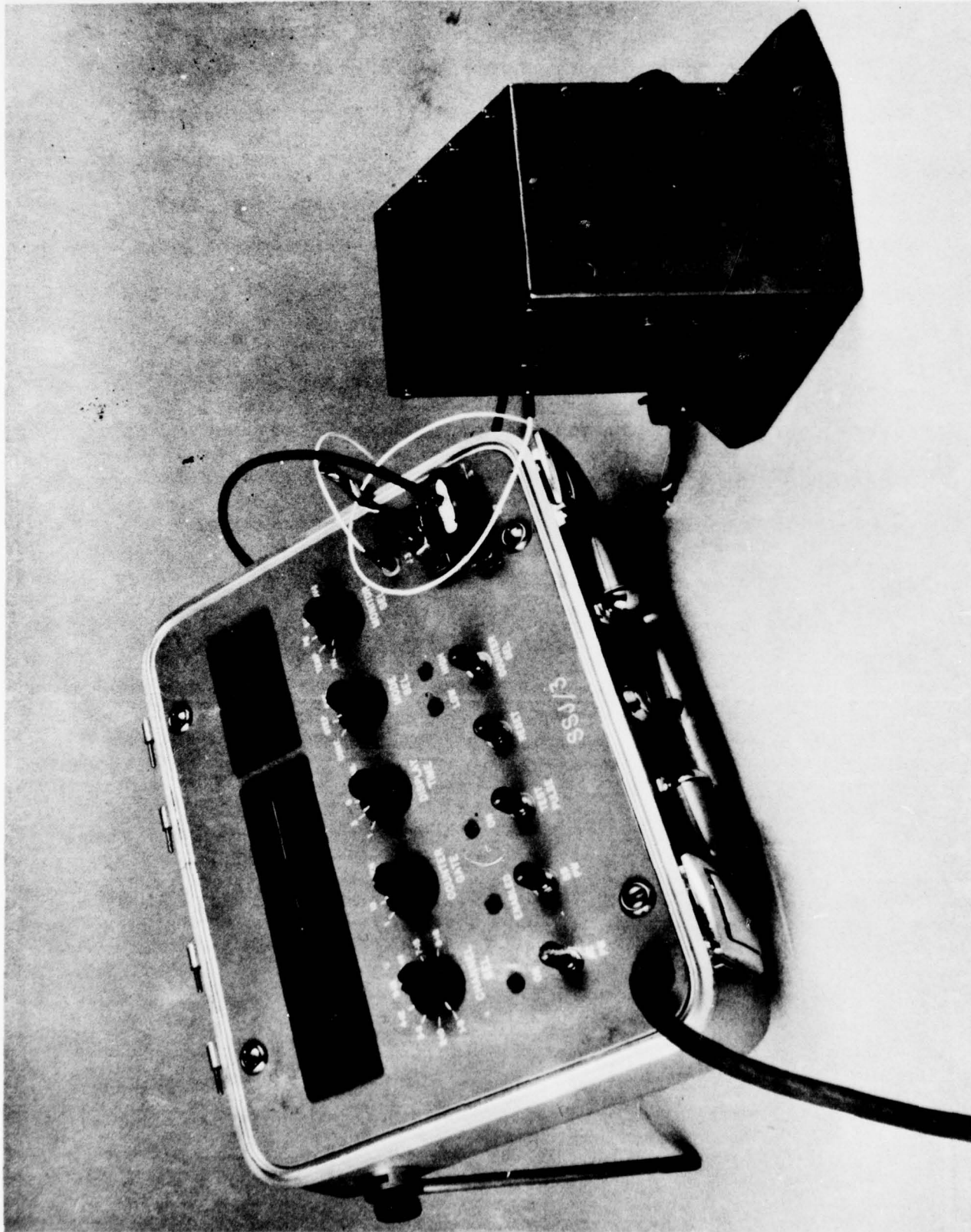


Figure 1

ELECTROSTATIC ANALYZER

This instrument employs two separate electrostatic analyzers of the curved (cylindrical) plate variety. This type analyzer uses a variable electric field between two curved plates to effect energy analysis. The collimators and entrance and exit apertures are arranged such that to be counted electrons must follow a very nearly circular trajectory through the radial field between the plates. The energy in electron volts of a non-relativistic electron in such a trajectory is given by:

$$E = \frac{RV}{2d}$$

where: V = plate to plate potential in volts

R = mean radius of curvature of plates

d = plate separation ($R_1 - R_2$)

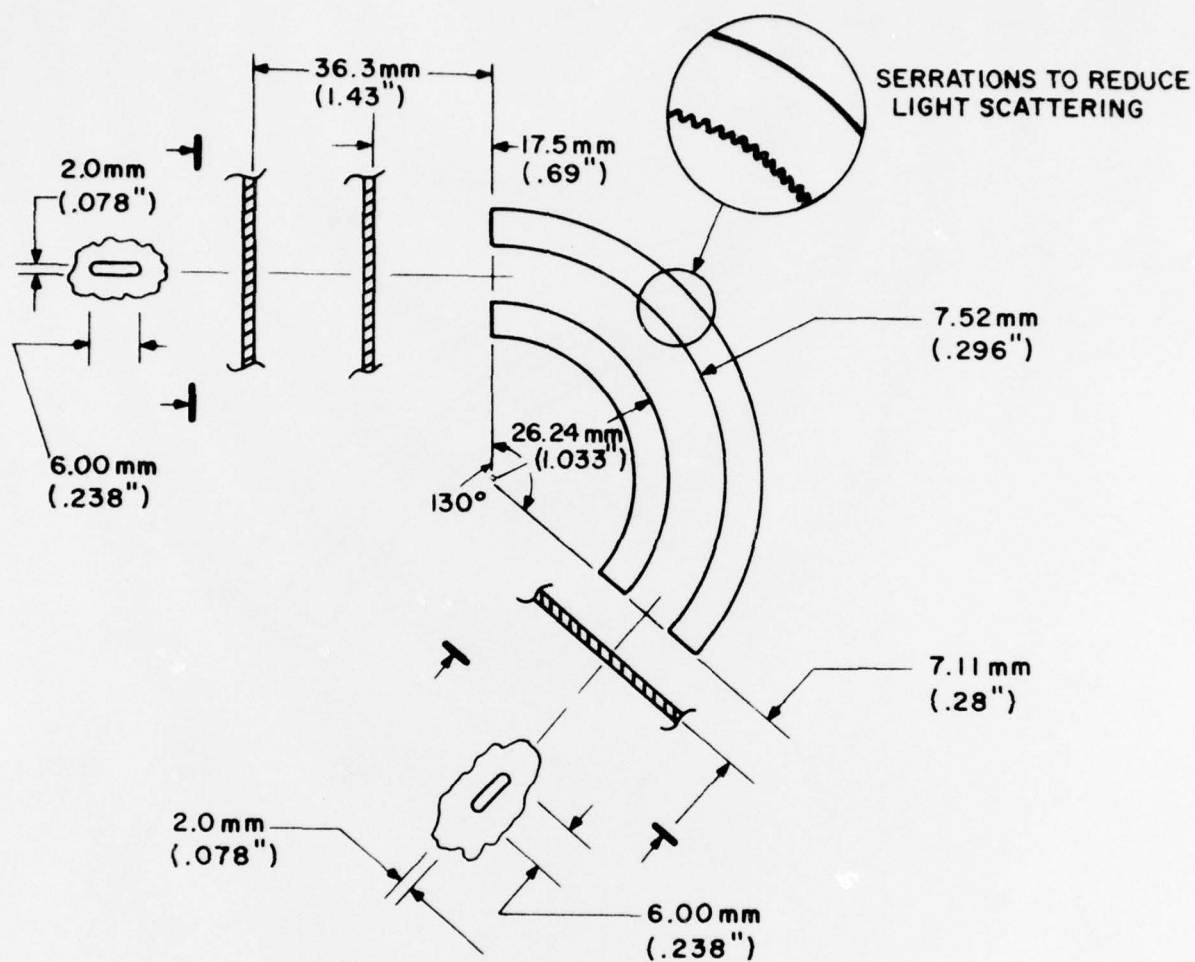
Thus, the energy of particles passing through the exit aperture is directly proportional to the difference in potential between the plates. The constant of proportionality, known as the "analyzer constant" is equal to $\frac{R}{2d}$. The analyzer constants for this instrument are 20 eV/V and 2 eV/V for the high and low energy analyzers respectively. The high energy plates are operated between ± 25 and ± 500 V, covering the energy range from 1 keV to 20 keV. The low energy plates are operated at half the high energy voltages (± 12.5 to ± 250) and cover the range 50 eV to 1 keV.

The balanced \pm configuration creates a zero potential surface midway between the plates. Since this surface passes through the narrow apertures, electrons undergo negligible

acceleration upon entering and leaving the analyzers.

The plates are aluminum with a sandblasted finish to minimize the amount of extreme ultraviolet reaching the Channeltrons, which are sensitive to radiation in this part of the spectrum. Reflections from the small plates are further reduced by closely spaced serrations. The presence of dielectric materials between the plates or in the vicinity of their edges was avoided to prevent charge buildup which could affect the electron trajectories. This is shown in Figure 2, along with dimensions and a list of the eight energy steps for the small ESA. Figure 3 is the large ESA, while Figure 4 shows the complete ESA assembly.

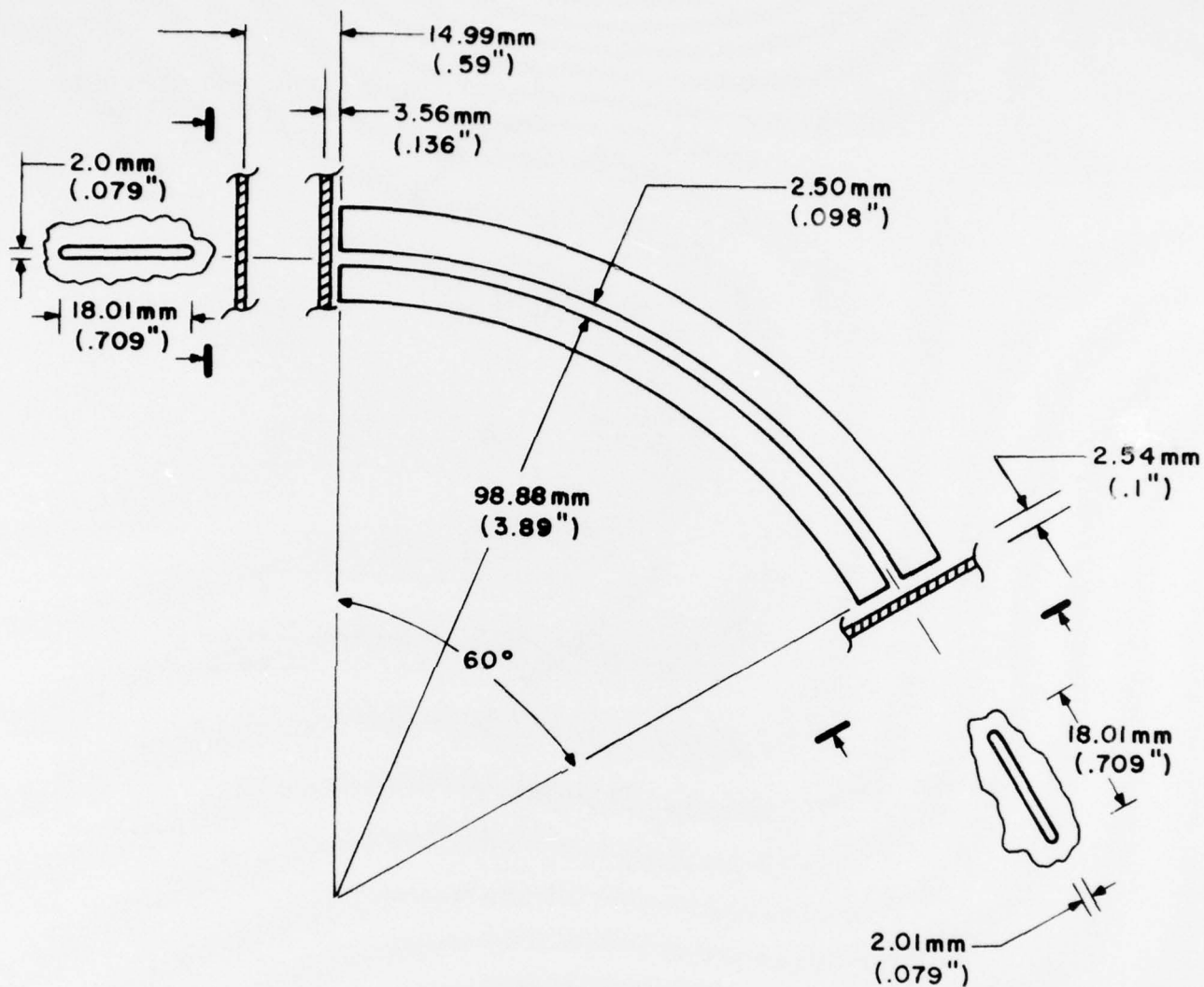
SSJ/3 - SMALL PLATES GEOMETRY



ENERGIES:	
1.	1045 eV
2.	661
3.	434
4.	264
5.	183
6.	110
7.	77
8.	51

Figure 2

SSJ/3 - LARGE PLATES GEOMETRY



ENERGIES:	
1.	20,000 eV
2.	13,700
3.	8,990
4.	5,500
5.	3,790
6.	2,290
7.	1,590
8.	1,060

Figure 3

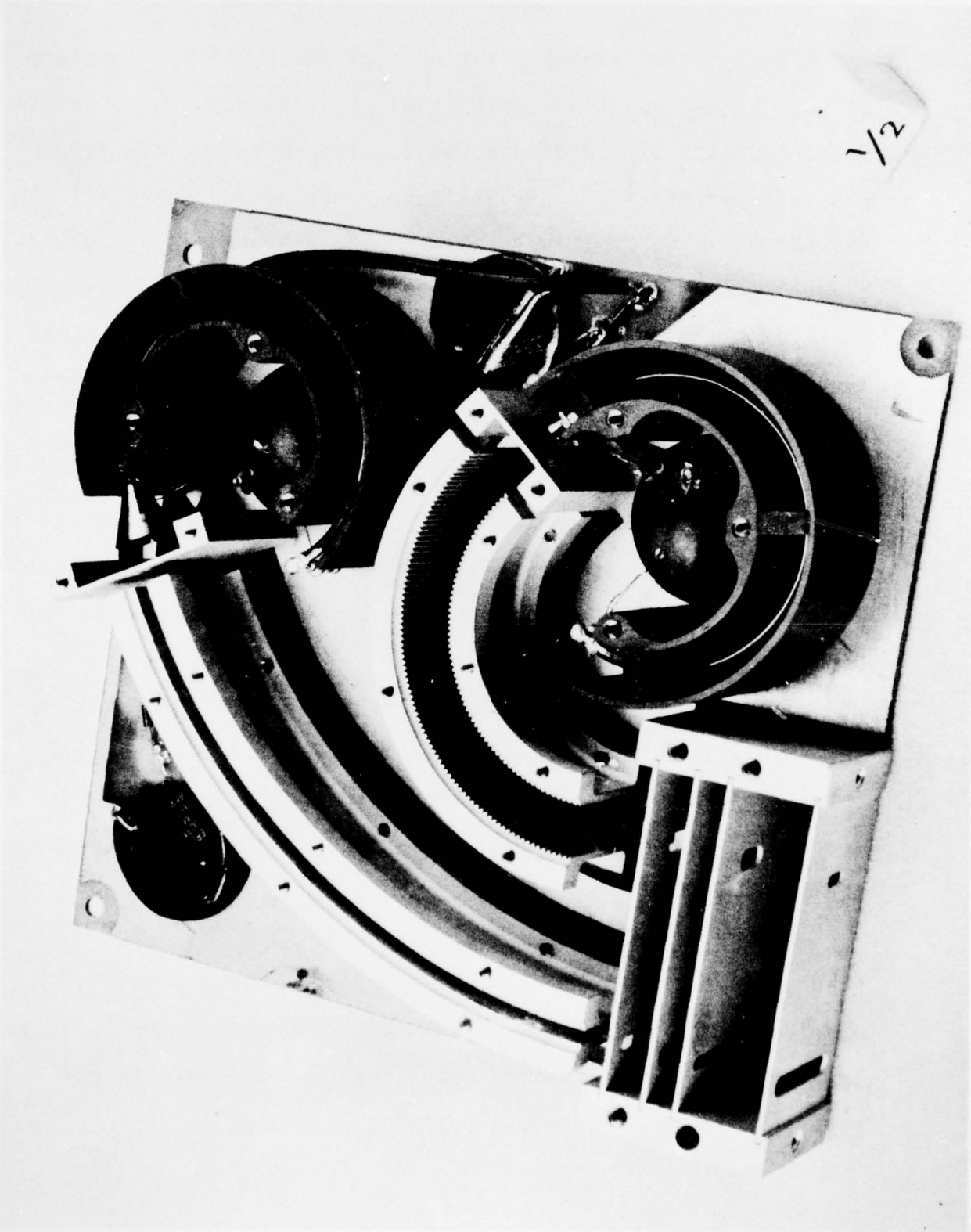


Figure 4

DETECTORS

The detector assembly for each of the two ESA's consists of two Channeltron Electron Multipliers manufactured by Galileo Electro-Optics of Sturbridge, Mass. Specifically, the large ESA uses two CEM 4019-C/WL-SC (10mm funnels) and the small ESA, two CEM4013-C/WL-SC (3mm funnels). These are high gain devices, producing an output **charge** pulse of 10^7 - 10^8 electrons about 20 ns in width. The two detectors for each ESA are connected in parallel with their anodes at +3 kV and their funnels at ground potential.

The Channeltrons used in this instrument have undergone special screening by the manufacturer to minimize the possibility of early failure. These units are expected to have a lifetime exceeding 10^{11} counts which greatly exceeds the predicted total count range for this instrument.

In order to eliminate solar XUV as a limiting factor on the Channeltron lifetime, a solar sensor has been included in the instrument to disable the power supply, and thus Channeltron bias, whenever the sun approaches the fields-of-view of the analyzers.

The instrument is tested and burned-in with flight Channeltrons in place. For this purpose a clean sorption and ion-pumped vacuum system is used, eliminating the potential problem of gain degradation resulting from exposure to oil vapors found in conventional systems.

The Channeltrons are shock-mounted with Viton spacers inside a hard anodized cylindrical aluminum mount. Care was taken to avoid potentially contaminating materials in the instrument which might cause long-term gain degradation.

CALIBRATION AND TESTING

Three SSJ/3 packages have been built to date. The first is a qualification unit; the last two, flight units. Two ~~more~~ flight units are under construction at the present time. Testing of the qualification unit consisted of DMSP specified qualification testing as well as a complete design verification. Subsequent units are tested to flight acceptance specifications and are functionally tested relative to the qualification unit.

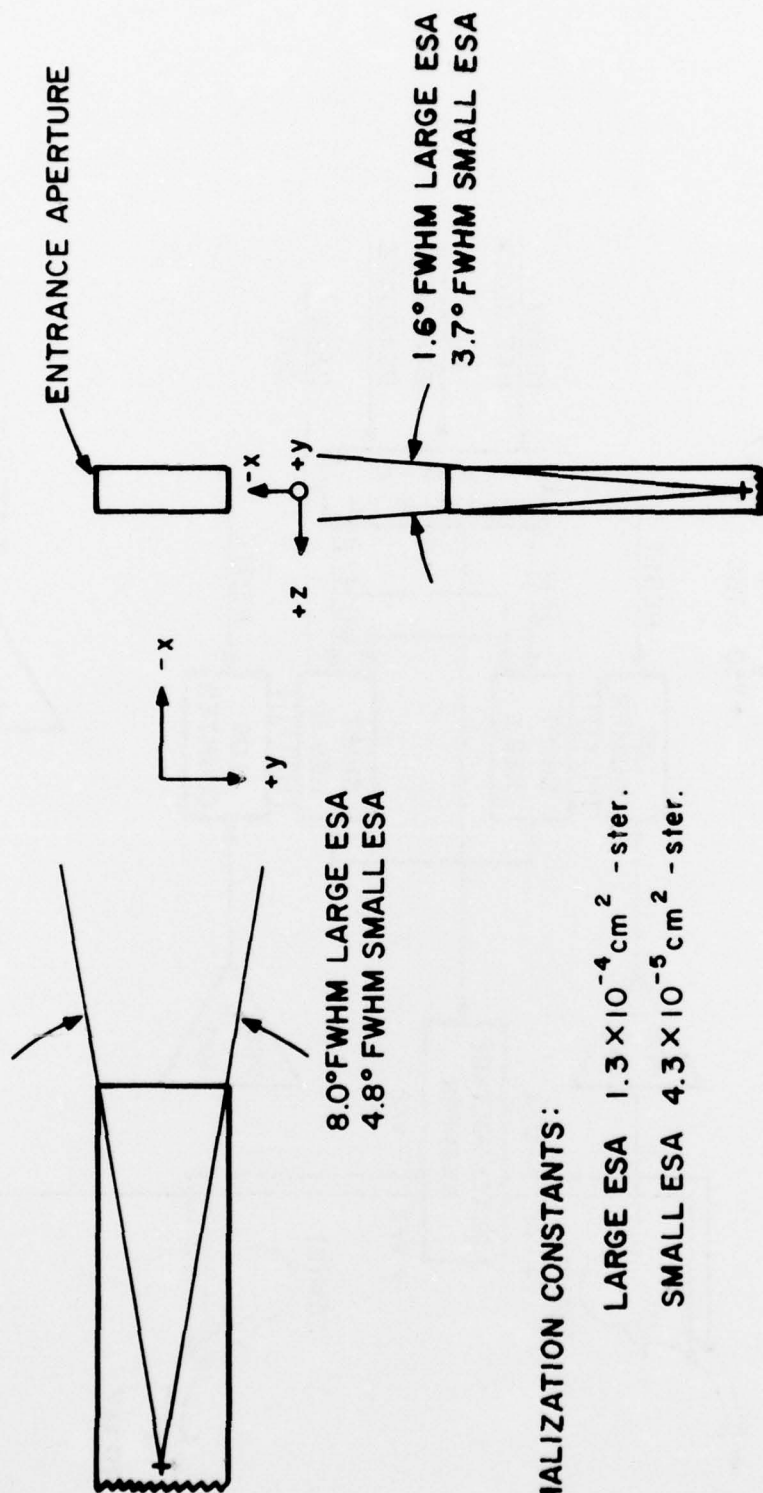
The initial design verification was performed at Aerospace Corporation where an accurately calibrated variable energy electron beam is available. The following parameters were measured and compared with design values:

- 1.) Angular response both across and along the apertures for all 16 energy levels.
- 2.) Geometric factor at all energy levels.
- 3.) Analyzer constant and energy level calibration.
- 4.) Energy resolution $\Delta E/E$.

Figure 5 indicates the physical parameters of the instrument.

The subsequent units are functionally tested by comparison with the first one. A Ni_{63} source was placed at a well defined location in front of the first instrument and its response observed. The same is done with the remaining units and their responses compared to that of the first one.

SSJ/3 PHYSICAL PARAMETERS



NORMALIZATION CONSTANTS:

LARGE ESA $1.3 \times 10^{-4} \text{ cm}^2 \text{ -ster.}$
SMALL ESA $4.3 \times 10^{-5} \text{ cm}^2 \text{ -ster.}$

$\frac{\Delta E}{E}$: LARGE ESA 4.0 %
SMALL ESA 7.2 %

Figure 5

SSJ/3 BLOCK DIAGRAM

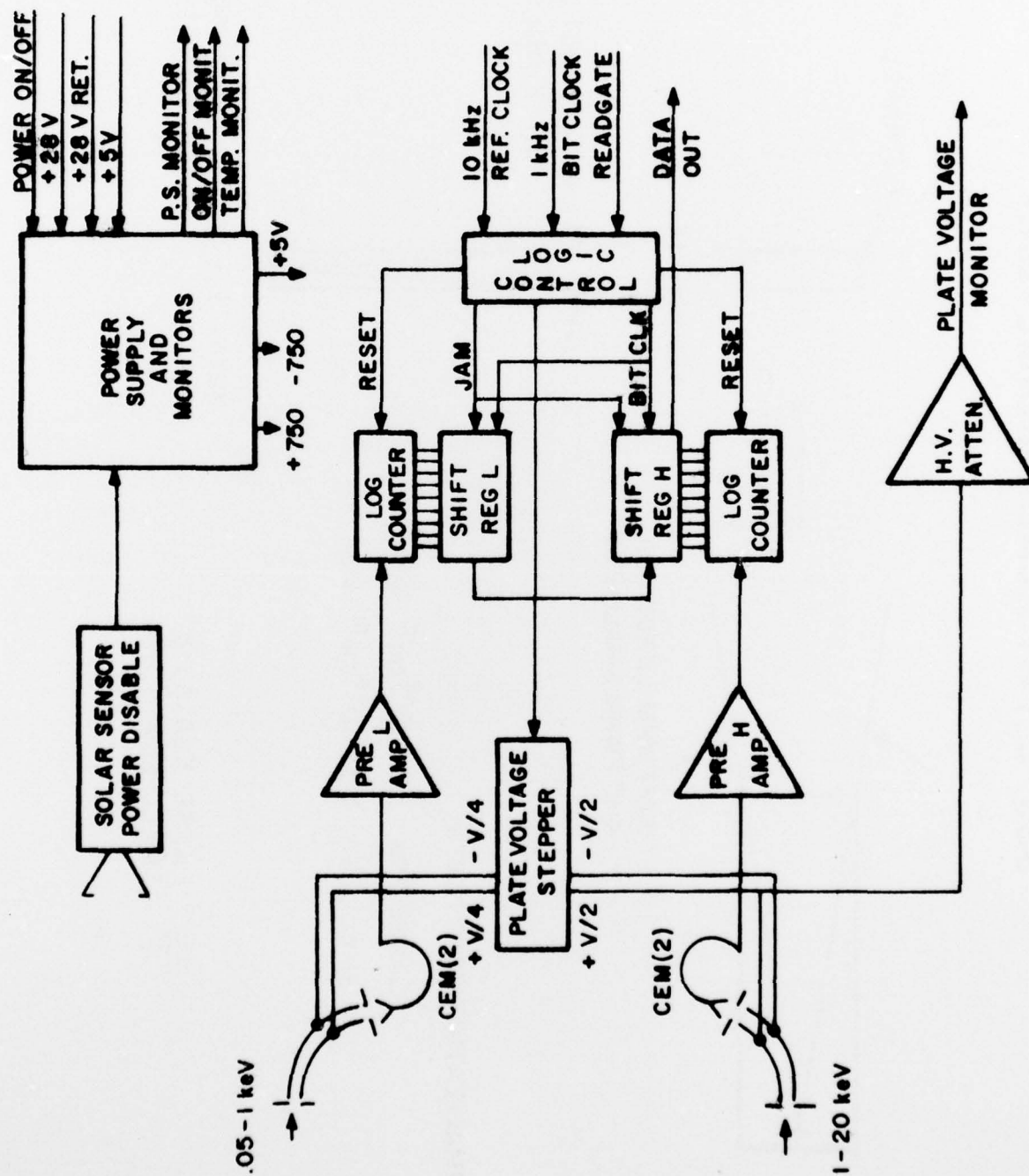


Figure 6

ELECTRONICS

Figure 6 is a block diagram of the instrument. The Channeltron outputs from each ESA are capacitively coupled to a preamplifier-discriminator. These units produce logic-compatible outputs which are counted by log accumulators. Timing and control logic steps the energy levels, resets and enables the log accumulators, and loads the data words in the shift registers. Upon receipt of the shift clock from the spacecraft once per second, the data words are serially shifted out on a single Data line. Figure 7 shows SSJ/3 with its analog and digital cards exposed. Brief descriptions of the functional blocks follow

Preamplifiers

The preamplifiers used in this instrument are of the charge sensitive type and have an inherent discrimination level of about .5 picocoulomb, corresponding to an electron gain of 3×10^6 . They include pulse forming circuitry which produces C-MOS compatible output pulses about .5 μ s long.

An externally accessible test input is provided to verify operation of the preamps, counters, and logic. This input couples an external pulse generator through a 2 pf capacitor to the preamp inputs. A fast-rising pulse of about .5 volt amplitude transfers enough charge into the preamps to produce output pulses.

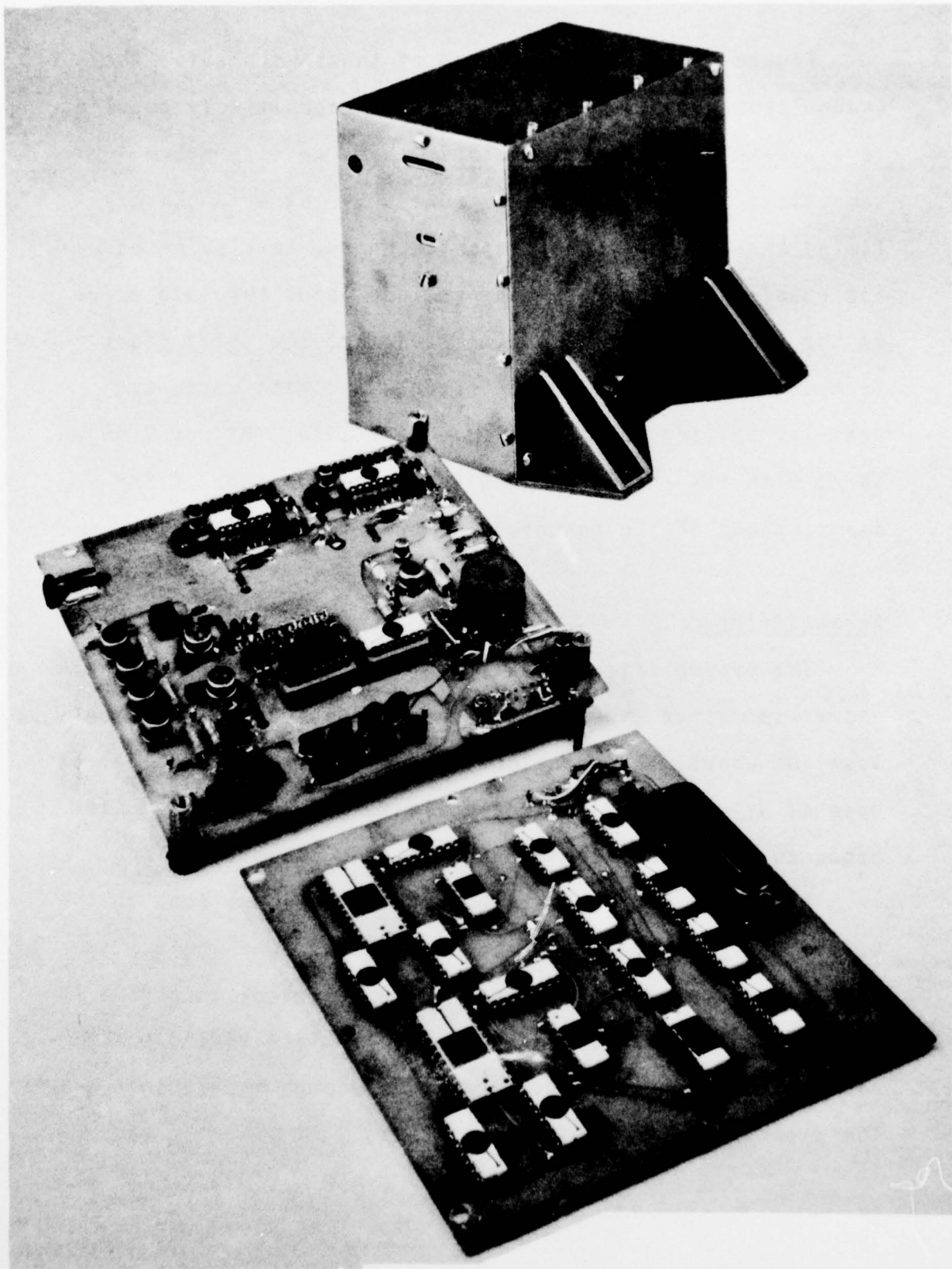


Figure 7

Log Counters

The electron count from each analyzer is accumulated in a log counter following the preamp. These units produce a 9-bit logarithmic representation of the actual count. The five least significant bits represent the mantissa and are the contents of a 5-bit binary counter. The remaining four bits, the exponent, represent the final prescale factor by which the input to the 5-bit counter is divided. The unit operates as follows: Initially, the 5-bit counter counts all incoming pulses, up to a count of 32, or 00000; then, the input begins to be divided by two, so that only alternate pulses increment the counter. When the counter again reaches the 00000 state, the prescale factor increases to 4. At each succeeding 00000 count, the prescale factor doubles, up to a maximum value of 2^{14} . The actual count represented by the 9-bit word is given by:

$$\text{COUNT} = 2^y(x+32)-33.$$

000000000
└───┬───┘
y x

The value 33 rather than 32 appears here because a 1 count is preset into each log accumulator at the beginning of every data interval to aid in readout verification. This count must be subtracted to get actual count.

The maximum capacity of these accumulators is 516,064 counts, which is well in excess of the maximum possible Channeltron output for a 98 ms counting period.

Control Logic and Data Output

At .1 second intervals the control logic generates a timing pulse derived from the 10 kHz Reference Clock provided by the spacecraft. This pulse initiates the following sequence of events:

1. The log accumulators are disabled and the voltage levels on the analyzer plates are decremented.
2. The two 9 bit data words present in the accumulator are shifted serially at a 10 kHz rate into two 72 bit shift registers.
3. The accumulators are reset to 000000001 and are re-enabled.

After a sequence of eight .1 second intervals the instrument stops counting and waits for the spacecraft supplied shift clock to read out the data. During this period the plate voltage returns from its minimum value to its maximum value, a step requiring about 15 ms settling time. The data is serially shifted out in one 144 bit block at a 1 kHz rate.

Upon completion of the data readout the 1 second cycle is complete and the eight step sequence begins again.

The logic consists entirely of standard C-MOS integrated circuits. Because of the sensitivity of C-MOS to radiation a special effort was made to shield all digital circuitry so that there is the equivalent of at least .25" of Aluminum in every direction.

Figure 8 shows the plate voltage sequence and Timing Diagram.

PLATE VOLTAGE SEQUENCE AND TIMING DIAGRAM

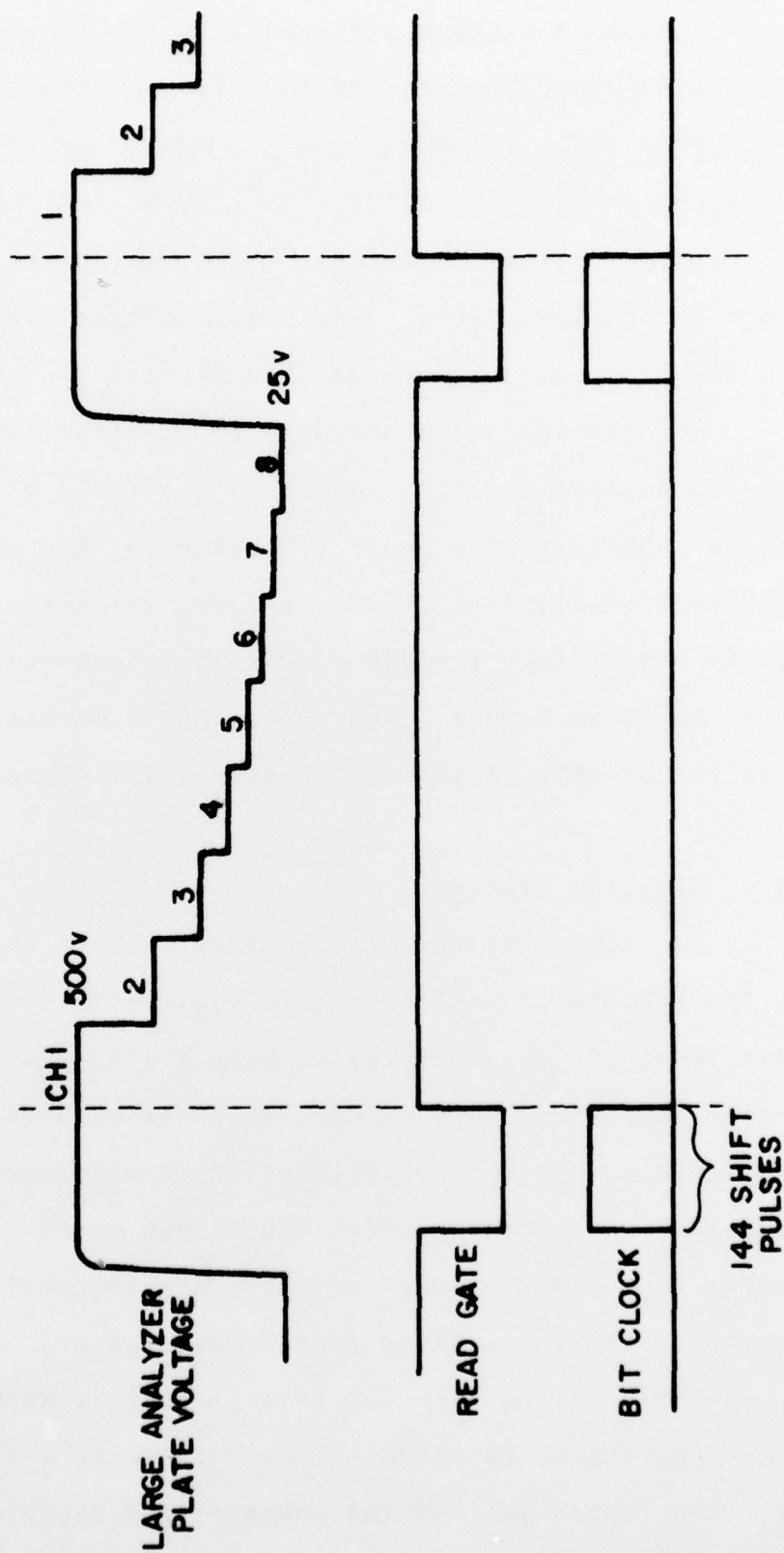


Figure 8

Power Supply and Solar Sensor

The SSJ/3 package utilizes a 50 kHz sine wave inverter type DC-DC Converter to provide all required power. This supply is built in-house. It supplies four regulated voltage levels: +5V; ± 750 V; and +3000V. +5V operates all analog and digital circuitry. ± 750 , which are derived from voltage doublers, supply the plate voltage stepper. +3000V is the bias voltage for the Channeltrons.

A solar sensor is provided to turn the instrument off during periods when the sun is in the field of view. The sensor consists of a photo transistor at the end of a collimator aligned with the analyzer collimators. The photo transistor, through a Schmitt trigger circuit, turns off the power supply. The same circuit is used for on-off control of this instrument by spacecraft command.

H.V. Stepping Circuit

The plate voltages are controlled by a shunt regulator using a chain of 4 high voltage field effect transistors as the shunt element. Employing only a single reference and error amplifier, this circuit produces balanced positive and negative outputs. The voltage levels are determined by fixed programming resistors which feed known currents into the error amplifier. These resistors are sequentially placed in the circuit by a Johnson-type C-MOS counter.

The settling time for this circuit is about 2 ms for the negative-going steps. This represents a 2% dead time for the instrument, as the counters are disabled for this period each tenth of a second.

ELECTROSTATIC ANALYZER (ESA)

SSJ/3 OR GFE3

Summary of Characteristics

Particles Detected	Electrons	
Detectors Used	2 Channeltron Electron Multipliers for each of the two sets of ESA plates	
Method of Energy Analysis	Voltage Stepping on ESA plates	
Number of Energy Bins	8 for each set of ESA plates; Total of 16	
Energy Bins	Large Plates	Small Plates
	20,000 eV \pm 3%	1,045 eV \pm 3%
	13,700 \pm 3%	661 \pm 3%
	8,990 \pm 3%	434 \pm 3%
	5,500 \pm 3%	264 \pm 3%
	3,790 \pm 3%	183 \pm 3%
	2,290 \pm 3%	110 \pm 3%
	1,590 \pm 5%	77 \pm 5%
	1,060 \pm 6%	51 \pm 6%
Acceptance Angles	Large ESA: 1.6° FWHM across the apertures 8.0° FWHM along the apertures Small ESA: 3.7° FWHM across the apertures 4.8° FWHM along the apertures	
Normalization Constants	Large ESA: $1.3 \times 10^{-4} \text{ cm}^2\text{-ster.}$ Small ESA: $4.3 \times 10^{-5} \text{ cm}^2\text{-ster.}$	
$\frac{\Delta E}{E}$	Large ESA: 4.0% Small ESA: 7.2%	
Data Rate	One complete Spectrum per second	
Dwell Time at Each Energy Level	98 ms.	
Digital Data Format	(9 bits per channel) x (16 channels) = 144 Bits	

ESA / SSJ/3 cont.

Note: Each 9 bits in every channel are in logarithmic form, the five least significant bits being the mantissa and the remaining four the exponent. This number is converted to decimal form according to the following relationship:

$$N = 2^y(x+32) - 33$$

Where; $\underbrace{0\ 0\ 0\ 0}_y, \underbrace{0\ 0\ 0\ 0}_x \leftarrow \text{LSB}$

Data Readout

The first bit to be read out is the least significant bit (LSB) of the highest channel followed by the next to the highest one etc., i.e.:

$\underbrace{000000000}_y \underbrace{000000000}_x \dots \dots \dots \underbrace{000000000}_y \underbrace{000000000}_x \underbrace{000000000}_y \underbrace{000000000}_x$ 1st bit out
 51 eV 13,700 eV 20,000 eV

[.....144 bits.....]

read out in one group
at the end of each second

Analog Monitors

Plate voltages: 5.0 volts to .25v
 Power supply : 2.5v
 Temperature : 2.5v at room temp.

Size

5.50in X 3.29in X 5.10in

Weight

3.046 lbs

Power Dissipation

.125 Watts

ACKNOWLEDGEMENT

The authors wish to thank Dave Nelson of Aerospace Corporation for his assistance in testing and design of this instrument.

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AFGL Report on "Calibration of SSJ/3 sensor on
the DMSP satellites".

